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UNCONVENTIONAL GAS RESOURCES

A RESEARCH PROGRAM IN COOPERATION WITH INDUSTRY TO REDUCE THE UNCERTAINTIES ASSOCIATED WITH THE SIZE OF THE RESOURCES AND THE METHODS OF EXTRACTION

United States Department of Energy
Morgantown Energy Technology Center

PREFACE

This document describes the program goals, research activities, and the role of the Federal Government in a strategic plan to reduce the uncertainties surrounding the reserve potential of the unconventional gas resources, namely, the Eastern Gas Shales, the Western Gas Sands, Coalbed Methane, and Methane from Geopressured Aquifers. The intent is to provide a concise overview of the program and to identify the technical activities that must be completed in the successful achievement of the objectives.

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by

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GAS AS AN ENERGY SOURCE

Natural gas, despite a 15-percent decline in production in the past 5 years, remains the largest contributor to domestic energy supply. Continued decline in gas production will increase reliance on imported oil and gas. If more of this clean, versatile fuel becomes available, the decline could be offset and gas could be diverted to industrial users of oil, thus reducing oil imports. Production from unconventional gas sources could play an important role in achieving this goal. Moreover, a supplemental gas supply could assure industry of an uninterrupted process source which should maintain and perhaps expand gross productivity.

Natural gas accounts for about one-fourth of the nations energy requirements. In recent years, demand for natural gas has been restrained to the level of available supply by nonmarket factors such as residential hookup moratoria, regulations on industrial and electric utility use, and in extreme cases curtailments. Recent projections indicate that constrained gas demand will remain at the current level of about 20 Tcf at least through the 1990's. Unconstrained demand could be considerably higher; the American Gas Association has estimated a gas demand of 25-30 Tcf by 1990 if constraints were removed. Thus, gas consumption is expected to hold constant or to increase, depending on availability of supply and gas-use regulations.

However, domestic production and reserves -- dominated by conventional gas resources -- have declined steadily. Production in 1978 was 19.3 Tcf, down from the 1973 peak of 22.6 Tcf. Reserves have dropped to 200 Tcf from their 1967 peak of 293 Tcf. In only 1 year since 1976 have additions to reserves kept pace with depletion of reserves through production. (That year was 1970, when the associated gas reserves of Prudhoe Bay were "booked.") The ratio of reserves to production for the lower-48 states at the end of 1978 was an all-time low of 8.8 to 1, compared to almost 15 to 1 only a decade earlier. Reserve additions (excepting Prudhoe Bay) have replaced only 46 percent of withdrawals during the 1970's.

This serious decline in production, reserves, and production-reserve ratios has continued despite a nearly tripling of average natural gas price (in real terms) since 1973, the emergence of still higher price intrastate markets, and a corresponding doubling of exploratory effort. Additions to reserves per successful exploratory well drilled since 1970 have decreased from 10.7 to 2.3 Bcf/well. Costs in conventional gas resources in the two areas for which a reevaluation is complete resulted in a 60-percent decrease in the estimated recoverable resource. The prior estimate was in 1974. Similar downward revisions have been made in estimates of inferred reserves for these areas.

These data point to sharply declining availability and rapidly increasing costs of conventional gas production from the contiguous United States. The phased decontrol and special provisions of the Natural Gas Policy Act of 1978 provide incentives for accelerated exploration, but the apparent decline in the number and quality of conventional gas prospects suggests that numerous supplementary gas sources will be required to meet the demand of gas.

RATIONALE FOR CURRENT PROGRAM

National policy set forth in the 1977 National Energy Plan (NEP) calls for substantially increased domestic energy supplies at economically acceptable costs and identifies unconventional gas resources as potential increased natural gas supply targets. As a result, the DOE Gas Recovery Research, Development, and Demonstration (RD&D) Program has been established. Four large, unconventional gas resources have been identified as having significant potential for development and positive impact on future supplies (Figure 1). They are:

- The low-permeability (tight) lenticular and blanket-type gas sandstones of the Western United States.
- The gas-bearing Devonian and Mississippian shales of the Eastern United States in Appalachia and the Midwest.
- The natural gas present within coal seams and associated strata.
- The high-temperature, high-pressure (geopressured) aquifers of the Gulf Coast region.

NEED FOR FEDERAL INVOLVEMENT

Several reasons for Federal research and development activities in energy have been advanced. Two of these are particularly pertinent to the Federal role in the unconventional gas resources:

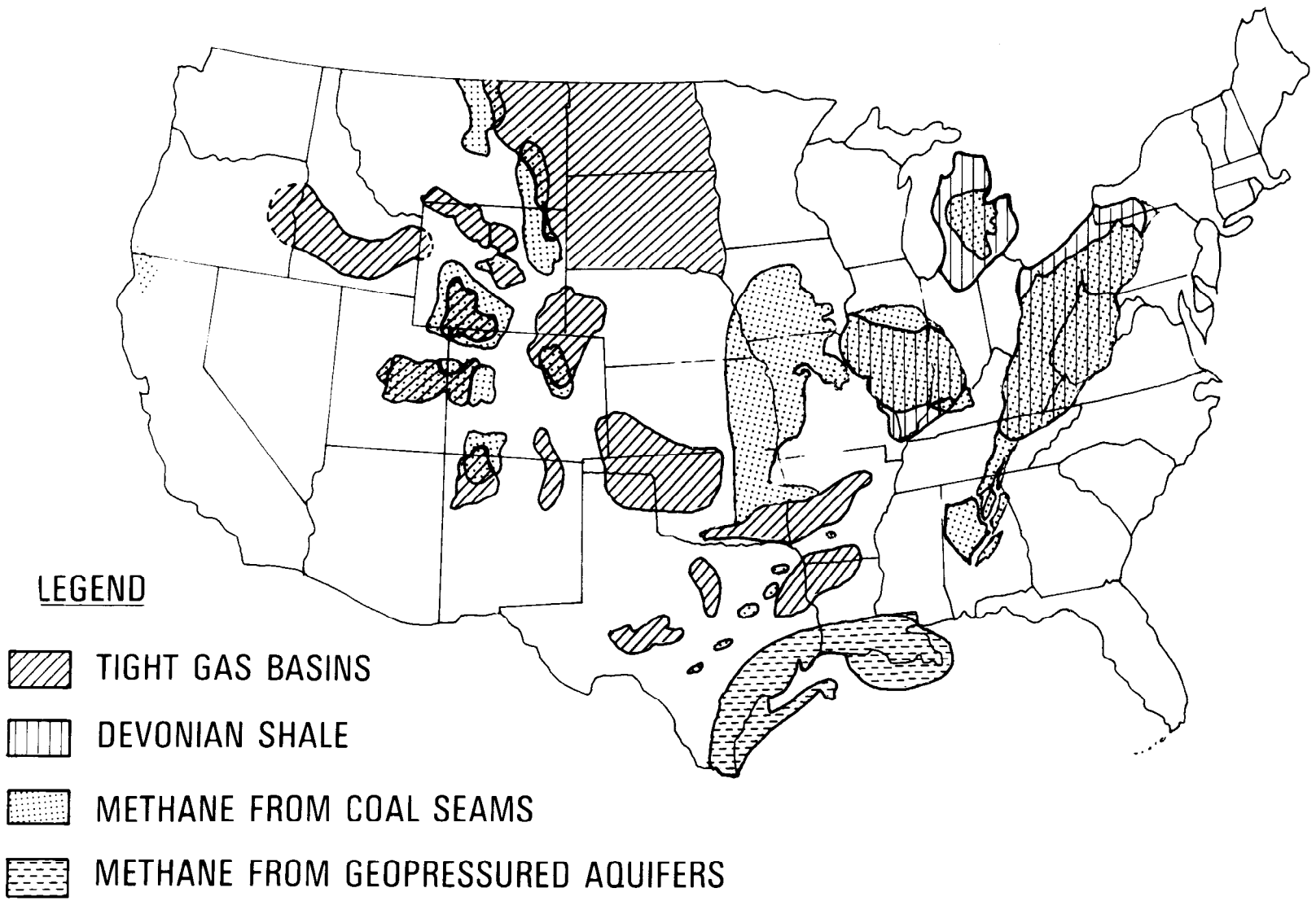
- Market forces may lead to a level of private R&D investment less than what is desirable from a national perspective.
- The Federal Government uniquely requires information for national and/or international energy policy formulation.

A close examination of the first reason shows that unconventional gas sources compete poorly for investment dollars with traditional exploration for conventional oil and gas. The substantial improvements in the performance of the technology required to improve the attractiveness of the unconventional resources relative to lower-risk gas sources, including foreign sources, require complex, expensive, and high-risk R&D. There is little that is patentable or licenseable and individual holdings are so small that the R&D cost per unit of production is high. Consequently, companies are reluctant to expend sufficient R&D funds to develop the technology required to produce any but the geologically most favorable unconventional gas resources. Industry R&D, to date and in the foreseeable future, therefore, is limited to high payoff, near-term efforts, mostly pursued through trial and error with little research.

Upon consideration of the second reason, it can be rationalized that the projected U.S. supply-demand situation compels the nation to provide for adequate gas supplies. The magnitude of the potential of the unconventional gas resources makes them one of the leading prospects, but the vast uncertainty surrounding this potential must be reduced if their proper role relative to alternative gas (and other energy) sources is to be assessed. Accurate assessment of the UGR potential could influence a number of controversial policy issues that

FIGURE 1

UNCONVENTIONAL GAS RESOURCES OF THE UNITED STATES



entail massive dollar commitments, long lead times, and even longer term consequences.

In the gas domain, the Federal Government is being called upon to guarantee completion of the Alaskan pipeline, guarantee completion and/or offer price support for surface gasification facilities, allow rolled-in pricing of any new gas supply, allow new LNG, Canadian or Mexican imports, allow industry and electric utilities to burn gas, and set gas pricing for residential, commercial, and industrial users. In the larger energy sphere, the issues include the nation's posture toward oil export and toward alternative energy sources. Gaining this information on UGR is essential for making prudent decisions on fundamental national energy policy issues.

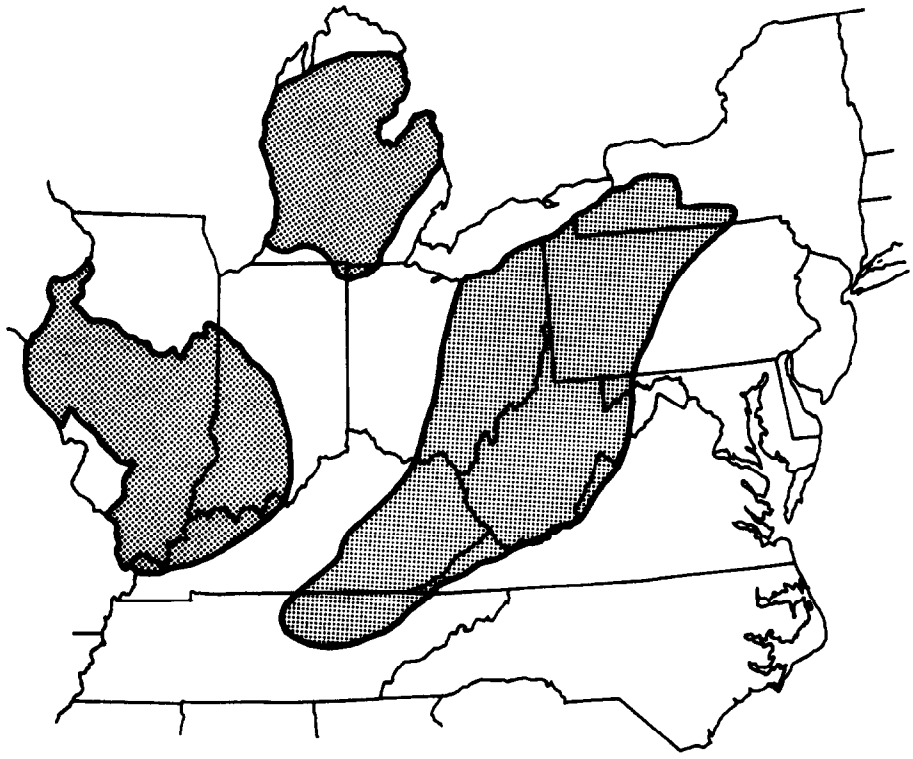
GAS PROGRAM GOALS AND OBJECTIVES

Goal 1: Develop and improve extraction technologies to the point of technical readiness for commercial development, i.e., increase the economic attractiveness of the unconventional gas resources to private industry. The objectives that support the technology improvement goal seek to increase the economic attractiveness of the unconventional gas sources to the private sector by decreasing risks, increasing reliability, reducing costs, and/or improving recovery efficiency.

Goal 2: Reduce the uncertainty surrounding the potential magnitude of reserves of the unconventional gas resources and the conditions under which they will be produced. From the policy perspective, the critical uncertainties concerning the unconventional gas sources largely focus on the overall rate of production over time at various costs.

The first goal is to complement and accelerate industry's R&D so that the fullest possible benefits of the unconventional gas potential are realized. The second goal directly supports policy decisions concerning the role of the unconventional gas sources in the nation's future energy supply.

EASTERN GAS SHALES



EASTERN GAS SHALES

The Eastern Gas Shales Project (EGSP) is a multidisciplinary research effort directed towards increasing natural gas production from the Devonian shales of the Appalachian, Illinois, and Michigan Basins of the Eastern United States.

The overall goals of the EGSP are (1) to develop the technologies that will establish effective and environmentally acceptable means for locating and producing natural gas from Devonian shales and (2) to reduce the uncertainty surrounding the potential magnitude of reserves so that the private sector will be encouraged to develop the resource on a large scale. Specific objectives of this project are:

- o Development of accurate estimates of gas-in-place and economically recoverable resources.
- o Development of exploration rationales for the identification of prospects.
- o Development and improvement of cost-effective extraction methods.

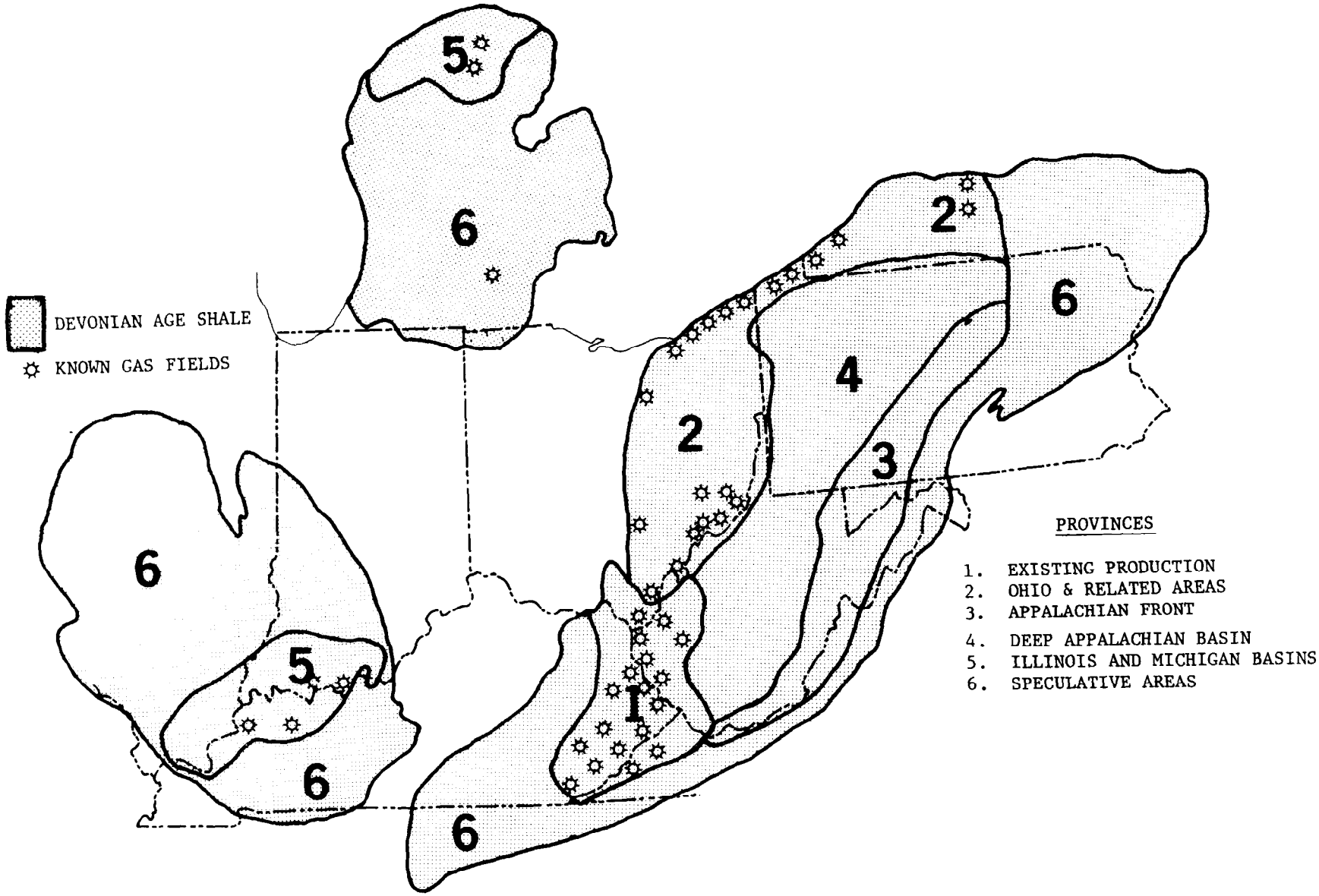
EGSP efforts during the first 4 years of the 9-year project have been directed at determining the geologic character and magnitude of the Devonian shale gas resource and toward increasing production of natural gas from this resource base. Almost all of the planned formation characterization work required to update the resource knowledge base has been completed. Geological evaluations are essentially complete to ascertain basin limits and stratigraphic targets as potential gas sources. With these developments, large areas of the Devonian shale have evolved as geologic provinces exhibiting certain characteristics that require particular technological developments for extraction. Accordingly, EGSP activities are planned for each geologic province (Figure 2), namely:

- ★ Productive areas of Kentucky and West Virginia.
- ★ Ohio and related areas in New York, Western Pennsylvania, and Northern West Virginia.
- ★ Appalachian Front in Pennsylvania, Maryland, West Virginia, and Virginia.
- ★ Deep Appalachian Basin in Pennsylvania and West Virginia.
- ★ Illinois and Michigan Basins.
- ★ Speculative areas in all Eastern states.

EGSP research has identified the nature of producible gas containment to be the micro-fractures and macro-factures of the shale formation. Knowledge of these fractures, their directionality, and density has enabled the development and testing of effective techniques to connect the gas-bearing natural fractures to the borehole. Tests of stimulation techniques in light of the geologic environment in the respective gas provinces have permitted the development of a rationale for stimulation strategy. The results of these pilot tests are undergoing systematic evaluation to permit refinement of R&D objectives. Initial economic analysis of Devonian shale stimulation ventures have been encouraging

FIGURE 2

EASTERN GAS SHALE PROVINCES AND FIELDS



and indicate that shale gas production should be technically and economically viable in some geologic provinces.

The EGSP is structured into the following functional categories or program activities:

- o Evaluation.
- o Resource and Site Characterization.
- o Research, Instrumentation, and Modeling.
- o Production Technology Development.

The first three activities provide for resource data acquisition and the development and testing of techniques for locating probable areas of gas-bearing natural fracture systems and for predicting the probable production from a particular stimulation method in a certain geologic province. The fourth activity is directed at the development and testing of cost-effective methods for extracting gas from the various geologic provinces in the shale. Specific task activities are discussed in the following sections.

Evaluation

The Evaluation activity in the project is designed to integrate facts as they develop, to assess recent technological developments and related industry activities, to ensure compliance with environmental regulations and address site-specific environmental problems, to develop a systems model for updating estimates of the potential resource, and to develop and monitor program plans that reflect the integration of the technical, geologic, economic, and other types of data.

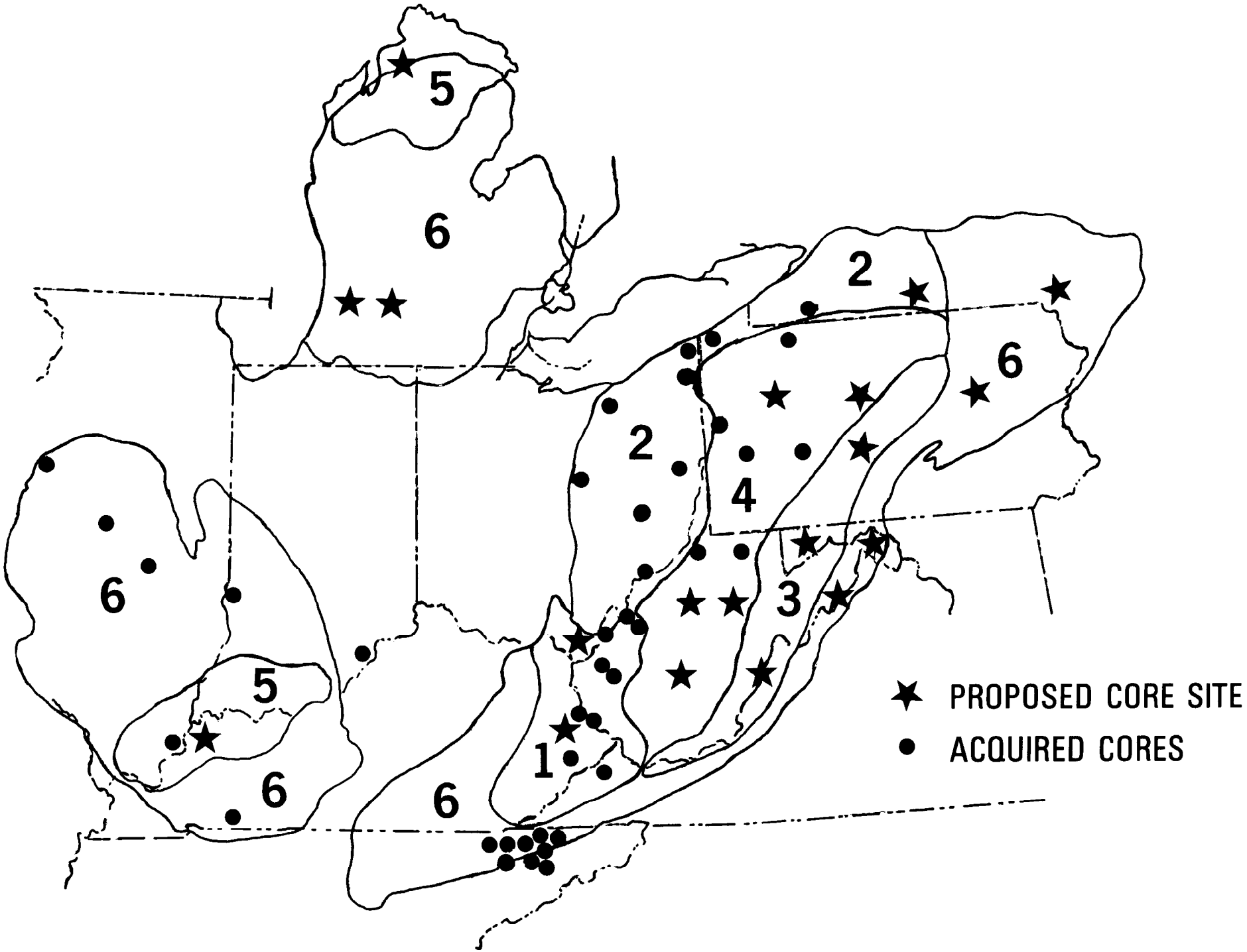
Accomplishments completed include an environmental impact plan for the project, economic analyses of stimulation techniques for the various basins, the establishment of a computerized information retrieval system and pilot resource assessment studies. The technology being developed in the project is being transferred to the private sector through symposia, an open-file library, semiannual progress reports, newsletters, publications, and presentations.

Resource and Site Characterization

This activity of the project is structured to develop the necessary resource data base for characterizing the Devonian shale provinces and to develop exploration rationales. Core information will be used to assess the potential of various resource areas, to guide modeling efforts, and to design stimulation tests (Figure 3).

Types of data collected include stratigraphic, structural, sedimentological, physical, and chemical data for identification of gas-bearing fracture systems. Field work consists of coring and logging to provide data for lab work. Laboratory research includes chemical, physical, elemental, and mineralogical studies to determine the stratigraphic sources of gas and the degree of fracturing in the reservoir. The needed data has been provided through contracts with universities and state geological surveys and the results were compiled and synthesized by the USGS for the varous geologic provinces. Shale characterization

FIGURE 3



EASTERN GAS SHALE CORE SITES

studies are being acquired through contracts to universities, research institutes, and private industry for province R&D efforts to develop and improve methods of locating gas-bearing naturally fractured reservoirs.

Research, Instrumentation, and Model Development

This activity in the project is directed at the development of new diagnostic tools, stimulation approaches, and predictive capability to accurately forecast reservoir performance whenever extraction methods are applied to particular geologic provinces in the Devonian shale. Meeting these objectives requires basic and applied R&D in the laboratory and the field and the development of models. The models serve to describe the present understanding of the stimulation processes, gas flow from the reservoirs, and economic parameters related to fracturing and production.

Types of achievements developed to date include the characterization of geologic provinces for susceptibility to water base fracturing fluids, the development of predictive codes for evaluation of stimulation techniques in specific geologic provinces and the verifications of a production performance model for the shale gas reservoir. The necessary developments were achieved through contracts with universities, DOE's national labs, and private industry. Synthesis of results are the responsibility of the Morgantown Energy Technology Center and its technical support contractor.

Production Technology Development

This activity in the project is directed at the development of effective stimulation methods for various geologic environments and to test these designs in field applications. The designs tested are conceptual models that have evolved from sequential laboratory and simulation studies. Detailed documentation of field tests under controlled conditions complemented with systematic well testing is conducted through cost-sharing contracts with private industry.

Field tests (16) and demonstration projects have shown that advanced stimulation technology (foam, cryogenic, MHF, and chemical explosive fracturing) will produce considerably more than conventional wellbore explosive fracturing in the gas province associated with historical shale production. Limited data (two wells each) for gas provinces 2, 4, and 5 preclude further establishment of new technology advances (Table 1). Particular emphasis is placed on the use of energy-assisted fracturing fluid for the low-pressure fractured reservoirs. Results of displaced liquid explosives are encouraging but as yet require further development. Directional deviated well technology is achievable but additional demonstrations are warranted in other regions to complete an economic assessment. The effectiveness of dual completion wells awaits the identification of geologic prospects in the province including Ohio and adjacent areas. Factors affecting production appear to be associated with frac length and reservoir permeability. Location of regions of increased fracture intensity is required to assure the likelihood of a commercial well. The stress ratio concept (minimum horizontal-vertical) is an estimator of fracture intensity in gas provinces. Together with siting wells adjacent to phototraces from aerial photography analyses, both exploration and exploitation testing in geologic provinces are in progress. They are:

TABLE 1

SUMMARY OF STIMULATION TESTS

COMPLETED:

NO / TYPE	GAS PROVINCES No/Average Flow INITIALLY MCFD 1	2	3	4	5	6
4 MHF	4 (255)	0	0	0	0	0
6 CRYOGENIC	3 (301)	1 (36)	0	2 (21)	0	0
8 FOAM	4 (207)	2 (150)	0	0	2 (283)	0
5 CHEM. EXPLOSIVES	5 (314)	0	0	0	0	0
23	16	3	0	2	2	0

SCHEDULED:

NO / TYPE	GAS PROVINCES 1	2	3	4	5	6
3 CRYOGENIC	0	3	0	0	0	0
31 FOAM	0	31	0	0	0	0
3 CHEM. EXPLOSIVES	0	3	0	0	0	0
8 SOLID EXPLOSIVES	8	0	0	0	0	0
45	8	37	0	0	0	0

Columbia Gas System -- A total of 10 wells have been drilled in Lorain and Trumbull Counties, Ohio, for production tests of new prospects in gas province 2. Comparative analyses of two stimulation techniques in each area are planned.

Mitchell Energy Corporation -- A total of 11 wells have been drilled in Gallia County, Ohio, in gas province 2 to test and verify a new exploration concept for locating gas-bearing fractured reservoirs. The concept is based on the depositional model for clastic sedimentation wherein natural compaction fractures are found along the flanks of the depositional highs.

Donohue, Anstey, and Morrill -- Three wells are planned for Noble County, Ohio, to test the production potential of prospects selected on the basis on seismic velocity lows which are indicative of naturally fractured reservoirs. The concept being evaluated is a new exploration technique applicable to all the geologic provinces in the shale. The project is a cost-sharing venture with Ohio DOE in gas province 2.

Donohue, Anstey, and Morrill -- An eight-well project for the Southern Tier Counties of New York is in progress to test the production potential of new prospects based on the exploration concept tested in Ohio. The project is a cost-sharing cooperative venture with NY ERDA in gas province 2. Stimulation techniques selected for testing will be based on site-specific geology.

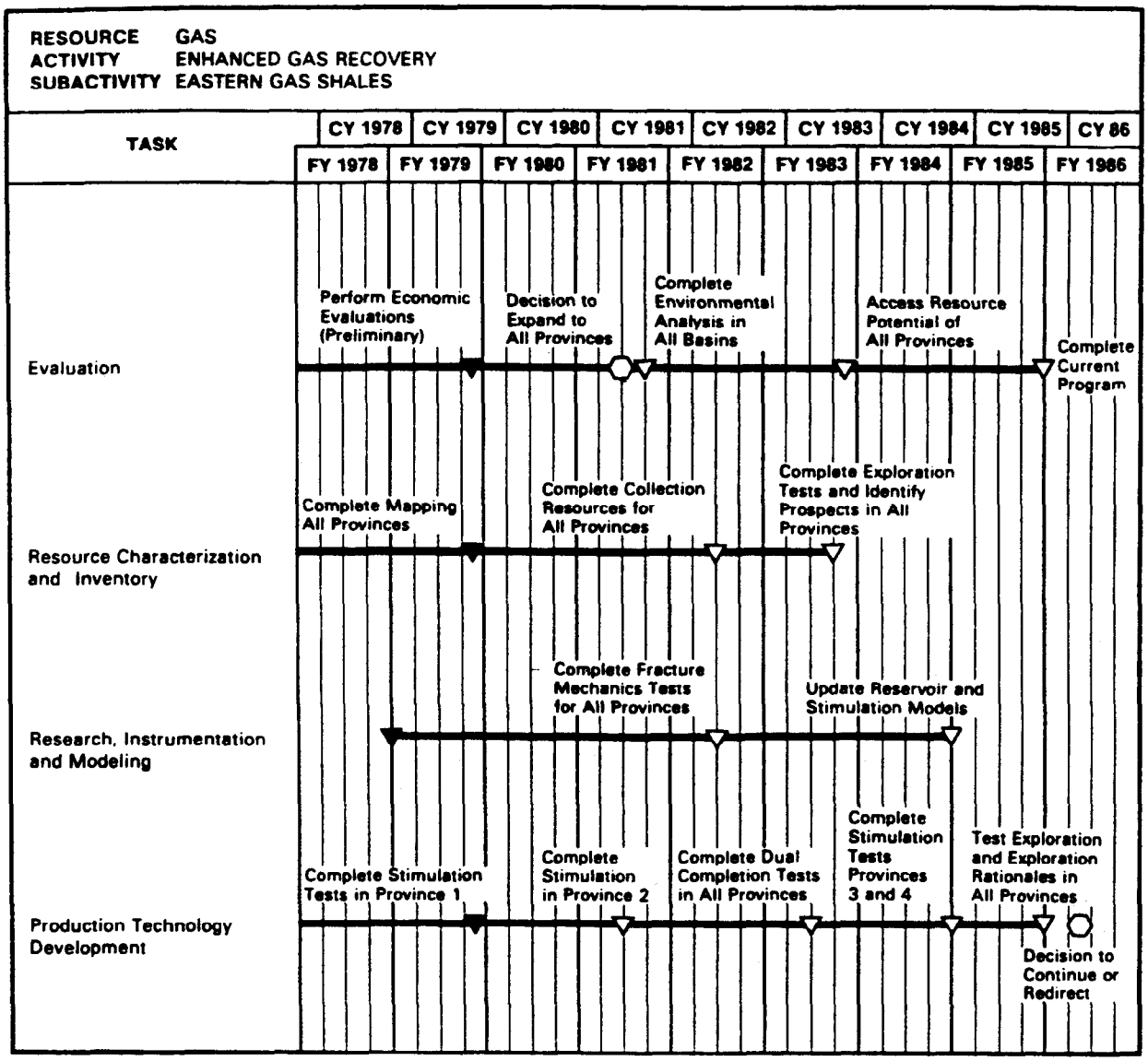
Thurlow, Weed, and Associates -- This contract is a four-well test program to determine the most effective means of stimulating gas production from the shale in the Knox County, Ohio, area of geologic province 2. Support for this test program has been obtained from Ohio DOE.

DuPont Corporation -- An eight-well test project in Putnam County, West Virginia, of geologic province 1 is in progress to evaluate the effects of an improved explosive fracturing technique in the peripheral area of established shale production.

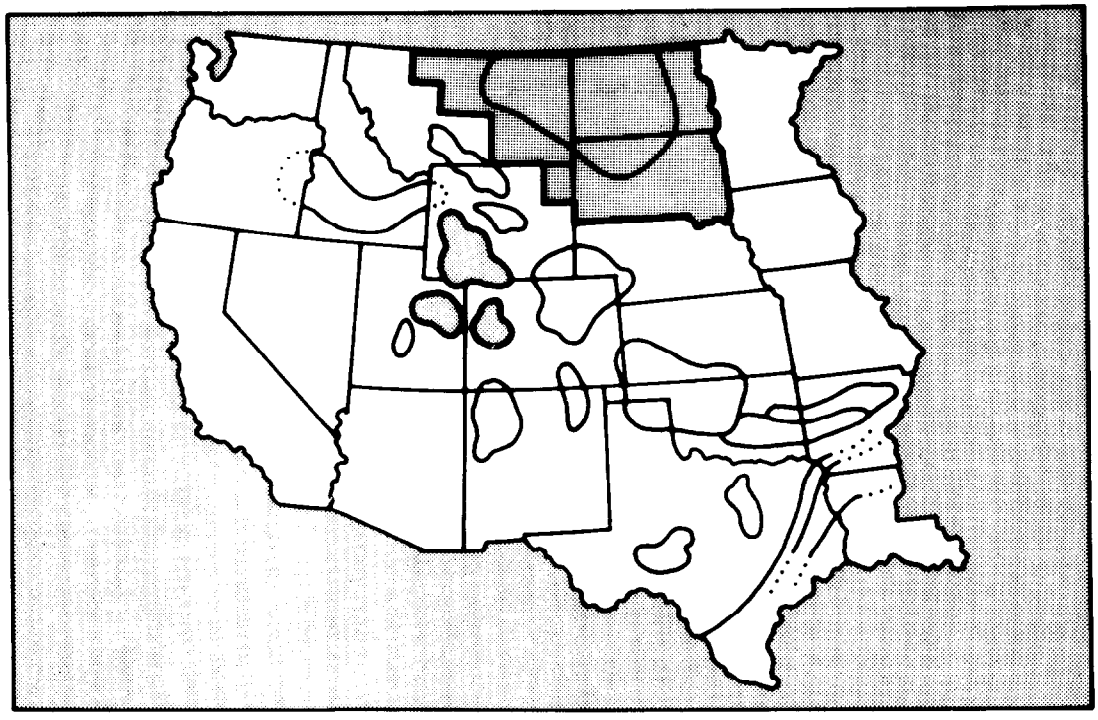
Additional requests for proposals are intended to investigate the production potential of areas identified as prospects in geologic provinces 3 and 4.

Detailed project plans and milestones for investigation of the defined geologic provinces are shown in Figure 4. Project efforts are intended to determine areal extent of potential gas producing regions within the outlined provinces and to quantitatively determine availability so that industrialists in relatively energy intensive activities might be able to plan for an uninterrupted or even expanded supply of natural gas.

FIGURE 4


RESOURCE GAS
ACTIVITY ENHANCED GAS RECOVERY
SUBACTIVITY EASTERN GAS SHALES
TASK
CY 1978
CY 1979
CY 1980
CY 1981
CY 1982
CY 1983
CY 1984
CY 1985
CY 86
FY 1978
FY 1979
FY 1980
FY 1981
FY 1982
FY 1983
FY 1984
FY 1985
FY 1986
Evaluation
Perform Economic Evaluations (Preliminary)
Decision to Expand to All Provinces
Complete Environmental Analysis in All Basins
Access Resource Potential of All Provinces
Complete Current Program
Resource Characterization and Inventory
Complete Mapping All Provinces
Complete Collection Resources for All Provinces
Complete Exploration Tests and Identify Prospects in All Provinces
Research, Instrumentation and Modeling
Complete Fracture Mechanics Tests for All Provinces
Update Reservoir and Stimulation Models
Production Technology Development
Complete Stimulation Tests in Province 1
Complete Stimulation in Province 2
Complete Dual Completion Tests in All Provinces
Complete Stimulation Tests Provinces 3 and 4
Test Exploration and Exploration Rationales in All Provinces
Decision to Continue or Redirect

WESTERN GAS SANDS



WESTERN GAS SANDS

The Western Gas Sands Project (WGSP) is directed toward accelerated exploitation of natural gas accumulations within "tight" sandstone formations of the Western U.S. These unconventional gas reservoirs contain large quantities of natural gas trapped in underground rock formations with permeability too low to permit recovery by conventional technology. Twenty basins have been identified as containing significant amounts of gas in such "tight" formations. These basins extend westward from the Cotton Valley Trend in Louisiana, through Texas and the Rocky Mountains, to the Uinta Basin of Utah, then north through the Northern Great Plains and Williston Basin, and ultimately into Canada.

In addition to their low permeability, these reservoirs typically have low-bulk porosities and high-water saturations, resulting in low gas-filled porosity. In many of these basins (i.e., Denver and Cotton Valley), the principal tight formations are broad, highly continuous reservoirs, or "blanket" formations. In others (i.e., the Green River and Piceance) the reservoirs are highly discontinuous lenses that sharply restrict the potential drainage of an individual well. Lenticular formations generally are more technically challenging with regard to gas extraction than blanket reservoirs with otherwise comparable properties.

Recent production from tight gas formations has been primarily from the San Juan, Denver, Cotton Valley, and Sonora Basins. The recent R&D accomplishments of industry made production in these basins possible and have also helped direct DOE R&D efforts to other more difficult basins.

To date, DOE R&D activities have been primarily directed toward the Greater Green River, Piceance, Uinta, and Northern Great Plains Basins. The technological problems associated with recovering gas from tight lenticular sands in these basins are more severe than recovery problems in many of the remaining 16 basins. The solution of certain technological problems will result in the recovery of a considerable amount of gas from these basins and will provide technological advances that are applicable to other basins.

An accelerated commercialization effort, providing additional funding is available, will concentrate on demonstrating early production potential from the blanket formations. The objectives are to delineate and characterize blanket formations wherever they occur in the 20 target basins and to demonstrate economic gas potential. Successful accomplishment of these objectives in the blanket formations will provide a reasonable expectation of significant production by 1990.

The WGSP has two primary goals: (1) the development of improved extraction technologies to a point of economic attractiveness to industry, and (2) a substantial reduction in the uncertainty presently associated with the total gas-in-place and that portion of the total which is economically extractable from these unconventional type reservoirs.

Achievement of these goals will require concerted and coordinated efforts in each of the following work categories or activities:

- o Data Acquisition and Evaluation.
- o Resource and Site Characterization.
- o Research, Instrumentation, and Modeling.
- o Production Technology Development.

These activities and their specific objectives are summarized as follows:

Evaluation

Reduce uncertainty regarding potential of the tight gas sands and direct program priorities toward realizing that potential.

- o Acquire and maintain existing geologic and technological data base.
- o Identify the technological problems that require Federal effort.
- o Identify environmental and other non-technical constraints.
- o Update estimates of gas-in-place, technically and economically recoverable gas.

Resource and Site Characterization

Provide sufficiently accurate geologic understanding of specific local sites to guide the design of effective extraction technologies; extrapolate from these results to support overall resource base estimates.

- o Perform basic geologic studies.
- o Perform detailed characterization of lenticular sand basins and other types of tight gas basins.
- o Core, log, and test wells of opportunity.
- o Develop detailed geologic descriptions.
- o Map and delineate occurrences of blanket formations in all basins.

Research, Instrumentation, and Modeling

Develop the tools, procedures, measurements, concepts, and models that are the required scientific components of the diagnostic, production, and environmental technologies necessary to economically produce natural gas from the tight gas sands.

- o Develop/improve geologic diagnostic technology.
- o Develop/improve stimulation technology.

- o Develop stimulation models.
- o Improve production testing capability and reservoir model(s).
- o Develop systems model.

Production Technology Development

Develop and test cost-effective means for recovering the gas from tight formations.

- o Perform single and multi-well experiments.
- o Perform field confirmation tests.
- o Specify stimulation design procedures for technology transfer.

Performance and completion of these activities provides for an integrated project approach toward achievement of the two main project goals. For example, Evaluation creates the estimates of the potential of each resource to serve the program's uncertainty reduction goal and, in so doing, defines the Federal role, direction, and priorities for the other activities. The next two activities prepare the components for developing the technology. The activity, Resource and Site Characterization, also provides geologic data to the Evaluation activity. Production Technology Development integrates these components in the context of field tests; the results of which feed back into the Evaluation activity for use in updating and redirecting the program. Several iterations of the program logic may be required before cost-effective technologies are developed to the level of commercial readiness. Project research activities to complete the established goals are illustrated in Figure 5 for future years.

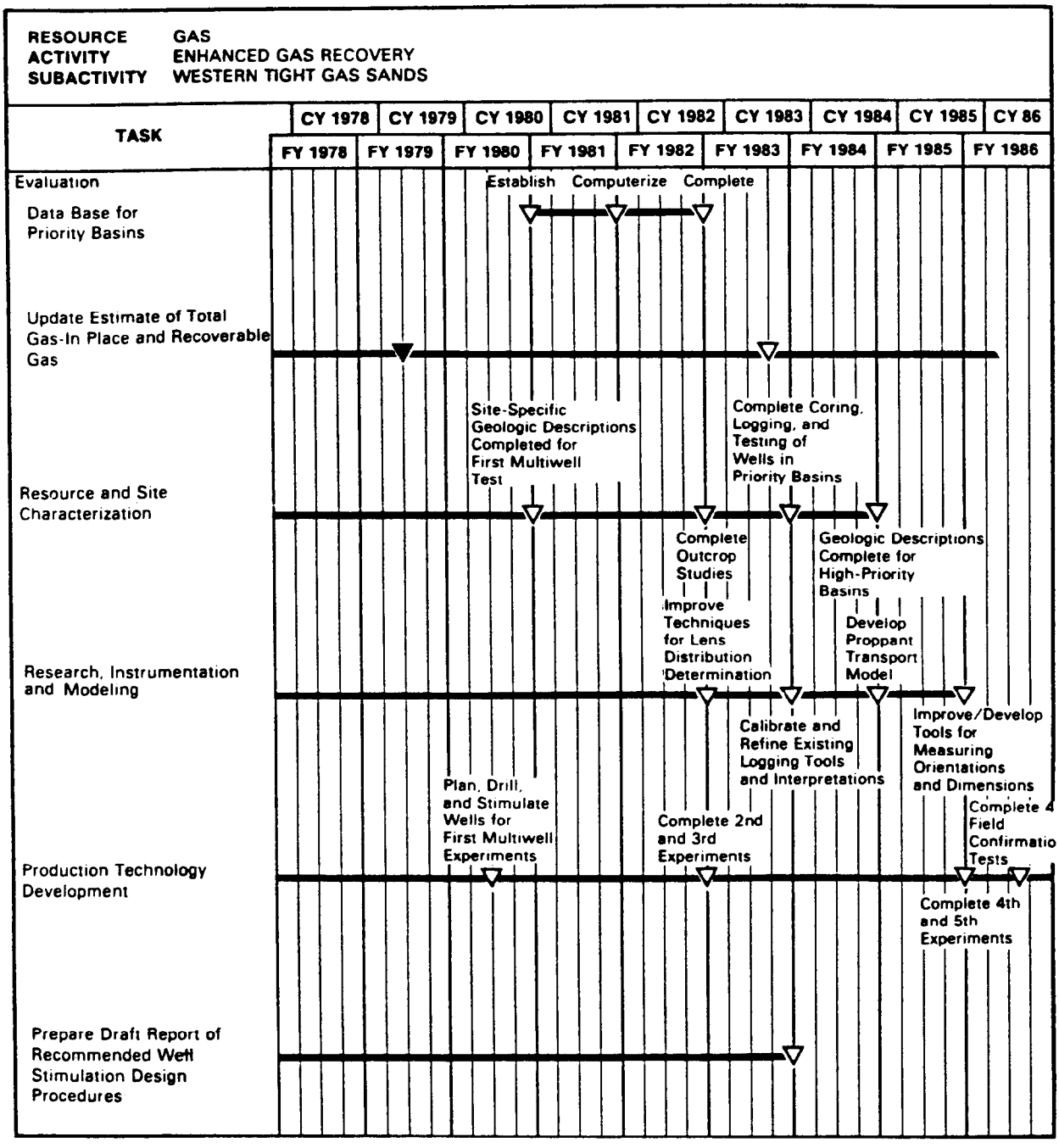
Each of these tasks contributes in a major way to at least one of the major program objectives. Given the current state of understanding of the tight gas sands resource and the technology for exploiting it, success in these R&D tasks will meet the program objectives and, through them, will result in economically attractive investment opportunities for industry and adequate estimates of the tight gas sands potential.

Accomplishments and Status

The R&D program in tight gas sands has been underway since 1974, when the first Government-sponsored MHF test was initiated in the Piceance Basin. In 1977, an intergrated program was developed; since then, three main activities have been funded by DOE in an overall effort to increase gas production from low-permeability gas sands:

- o Geological and geophysical studies to characterize the resource base in the priority basins. This work has been performed primarily by the USGS.
- o Research and development to improve mathematical models, to develop new instrumentation systems and data analysis techniques, and to better understand rock mechanics. This work has been performed primarily by the national laboratories.

FIGURE 5


RESOURCE GAS
ACTIVITY ENHANCED GAS RECOVERY
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TASK
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CY 1982
CY 1983
CY 1984
CY 1985
CY 86
FY 1978
FY 1979
FY 1980
FY 1981
FY 1982
FY 1983
FY 1984
FY 1985
FY 1986
Evaluation
Data Base for Priority Basins
Establish
Computerize
Complete
Update Estimate of Total Gas-In Place and Recoverable Gas
Resource and Site Characterization
Site-Specific Geologic Descriptions Completed for First Multiwell Test
Complete Coring, Logging, and Testing of Wells in Priority Basins
Complete Outcrop Studies
Geologic Descriptions Complete for High-Priority Basins
Research, Instrumentation and Modeling
Improve Techniques for Lens Distribution Determination
Develop Proppant Transport Model
Calibrate and Refine Existing Logging Tools and Interpretations
Improve/Develop Tools for Measuring Orientations and Dimensions
Plan, Drill, and Stimulate Wells for First Multiwell Experiments
Complete 2nd and 3rd Experiments
Complete 4
Field Confirmatio
Tests
Production Technology Development
Complete 4th and 5th Experiments
Prepare Draft Report of Recommended Well Stimulation Design Procedures

- o Field tests in the priority basins and other low-permeability basins to improve the application of stimulation techniques. These tests have been primarily Government/industry cost-shared projects.

Efforts to date in these activity areas have resulted in a firm identification of the problems associated with collecting diagnostic information in the low-permeability basins and with designing and carrying out stimulation treatments. Identification of pertinent problem areas has provided a great deal of guidance in the development of the current program.

A preliminary data base has been compiled for 13 of the 20 tight gas basins. Permeability, gas-filled porosity, net pay, thickness, and especially lenticularity are the critical reservoir parameters that determine gas producibility. Additional issues are introduced by uncertain mechanical and chemical properties of the rock and regional stress characteristics. Significant variation in reservoir properties within small geographic areas further complicates reservoir assessment.

The most promising extraction technology applicable to tight gas reservoirs is massive hydraulic fracturing (MHF). The purpose of this technique is to overcome the problem of low permeability by creating and propping open a fracture which penetrates deeply into the reservoir. This provides a conduit(s) for gas to flow to the well.

Fractures are created by pumping fluid (generally gelled water, foams, or polyemulsions) into the selected lithologic zone until the hydraulic pressure breaks the rock. As more fluid is pumped, the fracture extends deeper into the reservoir rock. Depending on the amount (up to one million gallons) and nature of the fracturing fluid, the fracture is believed to be propagated to distances approximately 500 to 2,000 feet (in both directions) from the wellbore (1,000 to 4,000 feet tip to tip). Due to earth stresses, the fractures tend to extend in the vertical plane, especially at depths greater than about 3,000 feet.

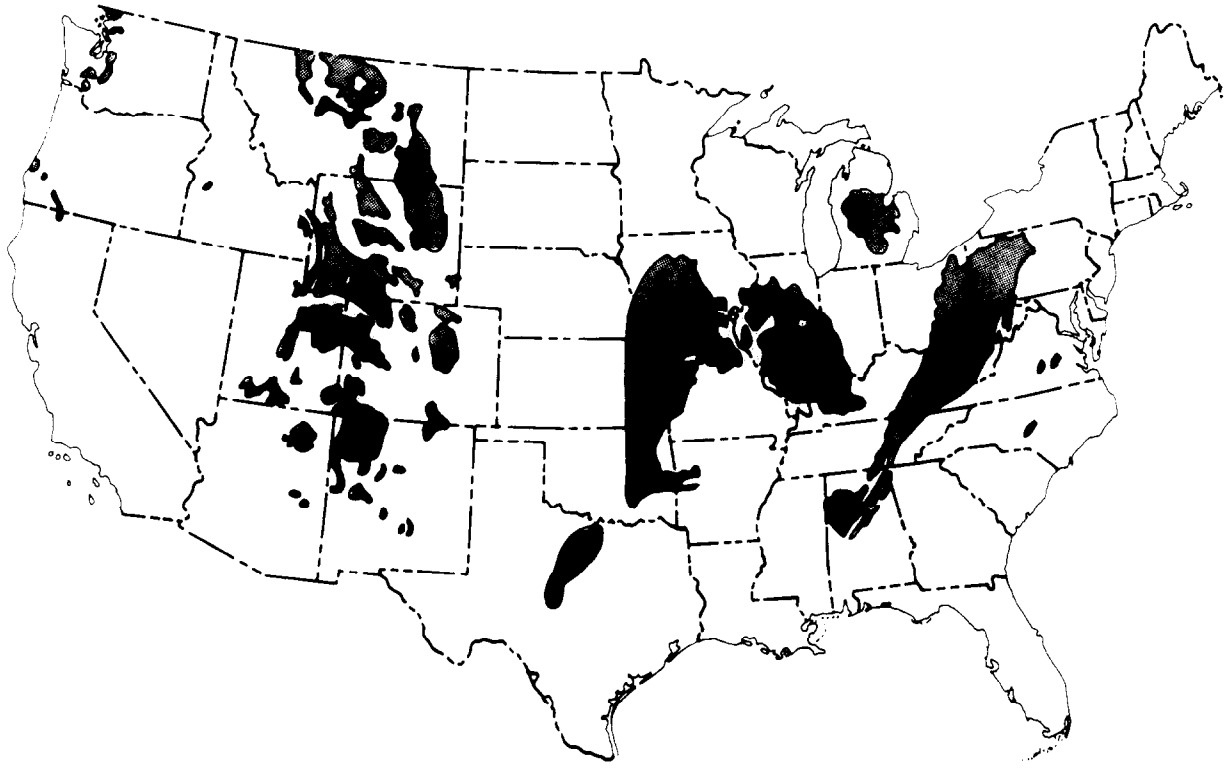
About 0.9 Tcf of gas per year, or about 4.5 percent of total domestic consumption, is produced from the tight basins currently. About one-third of this production is from zones with permeabilities that are near, but still below, conventional levels. This production represents a substantial increase in industry's interest in tight formations.

The two major "field" experiments scheduled for FY 80 are:

1. Colorado Interstate Gas: Dry Gas Injection Project, Wattenberg Field, Colorado.

2. Sandia/CER Corporation: Multi-Well Test Experiment, Piceance Basin, Colorado.

METHANE RECOVERY FROM COALBEDS



METHANE RECOVERY FROM COALBEDS

During the natural process of coal formation, methane (the principal constituent of natural gas) is generated and trapped in the coal seam as well as the adjacent rock strata. All coal deposits contain methane although the concentrations vary from seam to seam and within the seam. The total magnitude of the U.S. coal-associated resource has been estimated at approximately 800 trillion cubic feet (800 Quads). Given current and conservatively projected economic and technological factors, the recovery of some 300 trillion cubic feet of this resource appears readily feasible. This is equal to a 10- to 12-year supply based on present consumption.

The shortage of natural gas during the winter of 1976-77 focused attention on the urgent requirement to utilize this energy resource. Safety considerations in active mines have led to much development work by the U.S. Bureau of Mines of techniques for methane removal.

These techniques are now practiced by some mine operators with approximately 250 MMcfd of methane being emitted to the atmosphere. This gas is now being irretrievably wasted. The utilization of this valuable resource, including the methane available from "unminable"* coalbeds, is the objective of this task. The research, development, and demonstrations necessary for economical utilization are provided.

Due to the recent passage of the Natural Gas Policy Act of 1978, economics are becoming more favorable for commercial exploitation of this resource. There are, however, still many barriers to extensive recovery and utilization on a commercial basis:

- Although a variety of technologies and techniques give promise of profitable utilization of coal-associated methane, the technical, operational, and economic viability of these methods have not yet been sufficiently demonstrated to attract private investment.

- The quality of coal-associated gas varies from essentially pure methane for predrained gas, to variable combinations of methane and air for gob gas, to extremely diluted methane-air mixtures in ventilation air.

- Gas sources are generally located remotely with respect to demand and individual wells have relatively low production rates compared to this resource.

- Gas prices historically have been insufficient to attract interest to this resource.

- Although coal operators have a legal right to release methane in the course of mining, they are wary of the legal implications of gas recovery since, generally, natural gas rights are held by others.

- Since the market value of a ton of coal is on the order of 100 times the value of the methane contained therein, coal mining companies have scant interest in gas-derived revenues relative to their primary objective of coal production.

*"Unminable" those coalbeds not being presently mined because of economic or technical considerations.

Evaluation

The objectives of the Evaluation activity are: (1) to assess the results of the other activities, (2) to continue the development of the coalbed methane data base, (3) to assess recent technological developments and related industry activities, (4) to update estimates of the potential of the resource, and (5) to develop and monitor project plans that reflect the integration of the technical, geologic, economic, and other types of data that result from the project.

The Evaluation effort will involve:

- Analysis and Assessment of the Resource -- Evaluating resource properties, developing exploration methods, selecting target areas and drilling sites, updating estimates of the resource/reserves, and providing characterization test planning and analysis.

- Provide Project Information Management and Technology Transfer -- Provide for management of information resulting from the project and to make pertinent portions of this information available to all potential users.

- Provide Project Direction, Integration, and Support -- By identifying and initiating project support activities, identifying and analyzing constraints to exploitation of the resource, and by determining the economics of methane extraction/preparation and upgrading systems.

Resource and Site Characterization

The characterization of the methane content of our Nation's coalbeds has been done on a very limited basis, mostly in conjunction with active mining. Previous work includes only a small percentage of the coal resources and does not provide the knowledge needed to locate recovery and utilization projects in coalbeds with the greatest potential for methane production.

The resource and site characterization effort will involve:

- Acquisition of resource characterization from existing sources.

- Analysis and evaluation of existing data.

- Identification of potential recovery system sites.

- Acquiring Reservoir Geologic Data -- For the target reservoir areas, obtain the geologic data necessary to support evaluation and assessment of the coalbed methane resource.

- Core, Log, and Test Wells of Opportunity -- Perform core tests, logging, sample analysis, and flow tests (where possible) to obtain and correlate coal and methane data.

- Compilation of an all-inclusive data base for transfer to private industry.

The ranges of quantitative availability, gas quality, and geographic location of coalbed methane sources make it apparent that no single solution is appropriate for all cases. Recent studies conducted for ERDA (now DOE) and the Bureau of Mines indicate a high probability of economic gas recovery/utilization of several approaches, including direct pipeline injection, LNG production, on-site power generation, and petrochemical production. A variety of specific techniques and technologies have been considered under each of the preceding major headings. In some cases, off-the-shelf technology which could be modified for this application is available (i.e., gas turbines, LNG production units, and ammonia production units). However, further investigation, research, development, and demonstration is necessary.

The Methane Recovery from Coalbeds Project (MRCP) will develop methods and systems that establish technically and economically viable means for the recovery, conservation, and use of the methane gas associated with both minable and "unminable" (deep and/or thinly bedded) coalbeds.

Major project objectives include:

- o Location and characterization of methane resources.
- o Development of improved, cost-effective methane recovery and utilization technology.
- o Development of methane conservation techniques and systems.
- o Development of methane recovery prediction/projection techniques (models for well productivity).
- o Development of field tests for pilot systems.
- o Investigation of legal and institutional constraints.
- o Transfer applicable technologies to private industry.

The Methane Recovery from Coalbeds Project contains four primary activities summarized as follows:

1. Evaluation -- Reduce uncertainty regarding potential of the coalbed methane resource and direct project priorities toward realizing that potential.

2. Resource and Site Characterization -- Acquire sufficiently accurate geologic understanding of reservoir areas and specific local sites to guide the design of effective recovery technologies.

3. Research, Instrumentation, and Modeling -- Develop the tools, procedures, measurements, concepts, and models that are required scientific components of the diagnostic, production, and environmental technologies necessary to produce the methane from coalbeds.

4. Production Technology Development -- Design, develop, and field test cost-effective equipment and methods to produce gas from coalbeds.

The existing sources of public information on methane in coalbeds include the U.S. Geological Survey, U.S. Bureau of Mines, several state geological surveys, various universities, and private research foundations.

Some of the major contractors currently engaged in this research as of FY 1979 include:

- o Colorado Geological Survey,
- o Intercomp, Inc.,
- o TRW Energy Systems,
- o Utah Geologic and Mineral Survey, and
- o Iowa State University.

Research, Instrumentation, and Model Development

The objectives of this activity are to improve or develop new diagnostic techniques, to improve or develop new stimulation approaches, and to improve the ability to accurately predict and measure reservoir response to stimulation techniques. Fulfilling these objectives requires basic and applied R&D in the laboratory and the field and the development of models. Models and instrumentation will be evaluated and refined based upon the performance of tests conducted in the field.

Task and elements which support the Research, Instrumentation, and Model Development activity are listed below:

- o Conduct Extraction Technology R&D

  This task will continue throughout most of the life of the project.

  Develop/Modify Drilling Techniques and Equipment -- Drilling techniques include horizontal drilling and directional drilling, while equipment includes downhole motors and waterjet drilling.

  Perform Stimulation Experiments -- From single vertical boreholes perform multi-seam stimulations and completions. Design stimulations to maximize production but to minimize roof damage, especially in minable coal seams. Hydraulic, foam, gas, and dendritic stimulation designs will be tested.

- o Conduct Preparation R&D

  This task will continue throughout most of the life of the project.

  Develop LNG Conversion Capacity -- Develop equipment sized for cost effective liquification near the recovery site of gas from coalbeds.

  Develop Membrane Separation Capability -- Develop equipment and technique to upgrade low-quality gas from coalbeds so that it is suitable for pipeline injection.

Develop Mixed-Gas Upgrading Capability -- Develop equipment and techniques to remove contaminants from gas recovered from coalbeds to the extent that its use will be feasible and cost effective.

Production Technology Development

A number of techniques are available for producing methane from coalbeds:

- Drilling of vertical wells with the option to stimulate methane production using hydraulic fracturing techniques.
- Drilling of horizontal holes from the bottom of vent shafts or from the headings within the mine.
- Drilling of directionally controlled wells from the surface so as to intercept the major continuous fracture system (face cleats) within the coalbed.

None of these techniques has been developed to the degree that they are efficient and cost effective.

The objectives of the production technology development activity are to: (1) design, operate, and field test coalbed methane integrated systems; (2) investigate and resolve variables that will be encountered under field (operational) conditions; and (3) evaluate the systems/subsystems and operating methods tested for technical and economic feasibility and readiness for commercial ventures. The activity is in progress. Tasks and elements which support the Production Technology activity are listed below:

- Technology Test Projects Associated with Active Mine Coalbeds

  The elements of this task are a series of individual field test projects; each usually involves an integrated system.

  Multiple Well Projects -- Methane will be drained in advance of mining operations. New and improved gas extraction methods will be investigated (well spacing, geometric patterns, etc.).

  Horizontal Borehole Drainage Projects -- Methane will be drained prior to or during mining operations. New and improved equipment and methods will be investigated for horizontal borehole drainage.

  Advanced Systems Test Projects, (Minable Coalbeds) -- New equipment and methods will be field tested.

- Technology Test Projects Associated with Presently Unmined Coalbeds

  The elements of this task are a series of individual field test projects; each usually involves an integrated system.

  Deep Coalbed Drainage Projects -- Methane is extracted from deep coal horizons, many of which will not be mined in the foreseeable future.

  Drainage Projects in Coalbeds Under-Developed Areas -- Methane will be extracted from coal seams that cannot be mined because of their location

under-developed areas such as an urban community having multiple improvements on the surface.

Directional Drilling Coalbed Drainage Projects -- Methane drainage is accomplished using directional drilling techniques.

Advanced Systems Test Projects (Unmined Coalbeds) -- New equipment and methods will be field tested.

Utilization options for methane from coalbeds include space heating, power generation, and use as a chemical feedstock. Typical utilization system concepts include:

- o Direct injection into commercial gas transmission pipelines,
- o Conversion to LNG,
- o Heating,
- o Electric power generation, and
- o Conversion to ammonia.

Major research, instrumentation, and model development and production technology development ongoing in FY 1980 include:

Westinghouse Electric Corporation (Pittsburgh, Pennsylvania) -- Westinghouse was awarded a contract (FY 1977) to test the feasibility of operating a 600 KW turbine/generator on predrainage (in advance of mining) and "gob."

Mountain Fuel Resources,Inc. (Book Cliffs, Utah): Mountain Fuel Supply Company was awarded a contract (FY 1979) to demonstrate recovery and utilization subsystems relating to methane from a number of unmined coalbeds in the Uinta Basin, Carbon County, Utah. The 3-year contract will involve drilling a series of vertical wells, hydraulically fracturing the wells, monitoring reservoir performance, developing completion techniques, and perfecting predictive reservoir modeling of methane production. Any commercial quantities of gas will be compressed and injected into an existing nearby Mountain Fuel pipeline.

Westinghouse Electric Corporation (Pittsburgh, Pennsylvania): The Westinghouse Contract (FY 1978) involves testing the recovery technology of using multiple-seam, vertically drilled, and hydraulically fractured wells in advance of mining (predrainage of the methane). The produced methane is being utilized for space heating in a nearby plant and as a feedstock for fuel cell development.

Emerald Mine/H. F. Scott (Waynesburg, Pennsylvania): The Emerald Mine/H. F. Scott contract (FY 1978) is designed to establish the necessary procedures and to demonstrate the capability of directional drilling for coalbed degasification. Approximately 10,000 feet of horizontal directionally drilled borehole has been completed in a five toe "Birds foot" pattern (two of the toes extend 3,000 feet horizontally into the coal seam).

U.S. Steel Corporation, Oak Grove Mine (Jefferson County, Alabama): The U.S. Steel contract (FY 1975) initially involved utilizing approximately 28 vertical

boreholes near U.S. Steel's Oak Grove Mine for degasifying Mary Lee coalbed prior to mining. Seventeen of the boreholes have been completed in a degasification grid test pattern. Current production from this well pattern is well over 1 MMcfd of methane and 400 bpd of water. Plans have been completed for pipeline utilization of the produced methane to be implemented in FY 1980. It has been shown in this mine that total methane gas emission can be reduced by over 40 percent in mine sections containing vertical gas drainage holes given 1 year of predrainage activity.

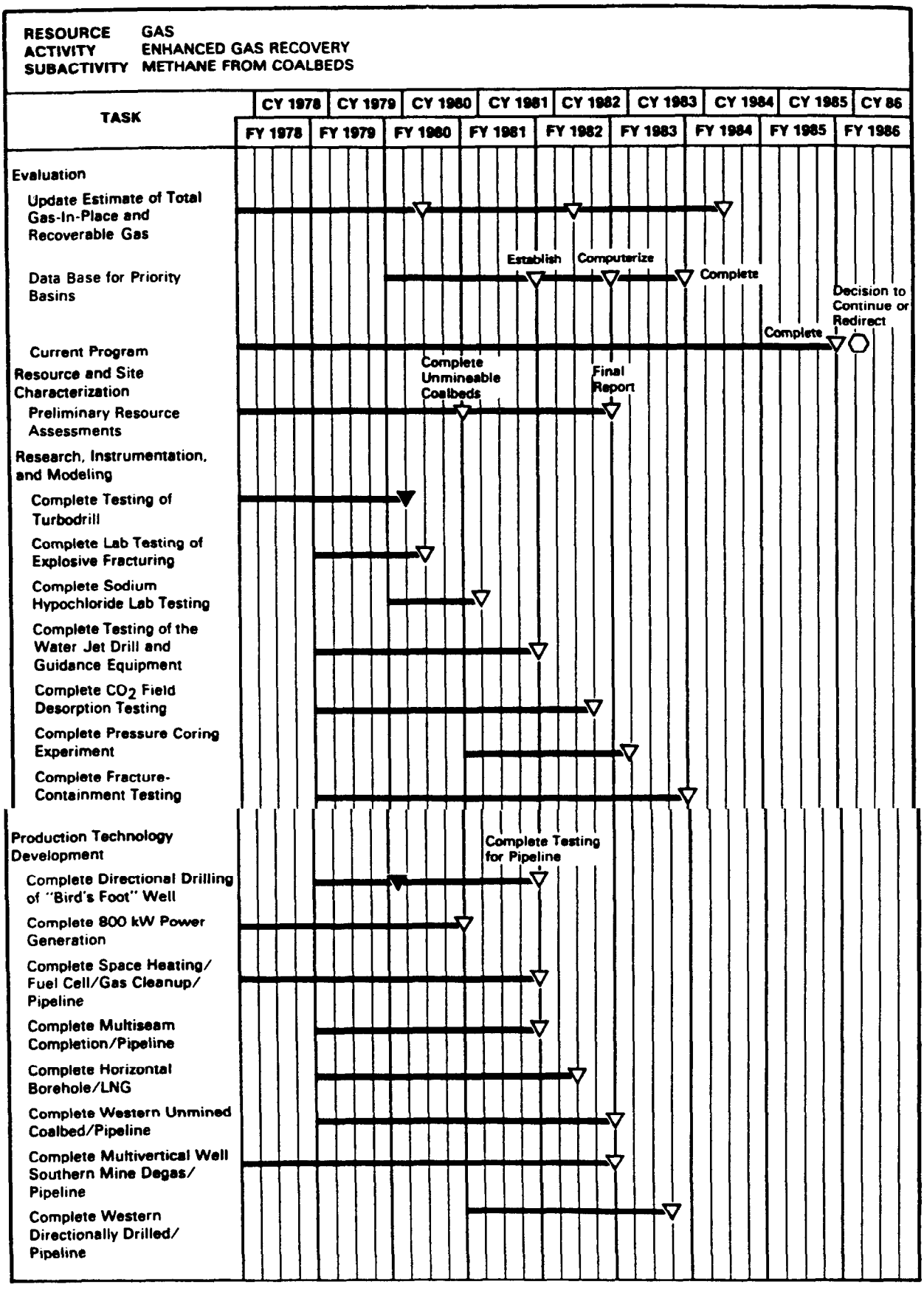
TRW Energy Systems, Inc. (Morgantown, West Virginia): TRW is an integrating contractor for selection, design, and coordination of the resource characterization effort and several recovery/utilization systems. Technology projects have been initiated in both mined and unmined coalbeds (FY 1979).

- Occidental Research/Island Creek contract involves the use of multiple horizontal boreholes in a longwall mine development program. This project includes several technology developments including the development of a drilling technique for long boreholes (greater than 2000 feet) to drain the entire length of a longwall panel. The gas drained by this project will be utilized to produce LNG.

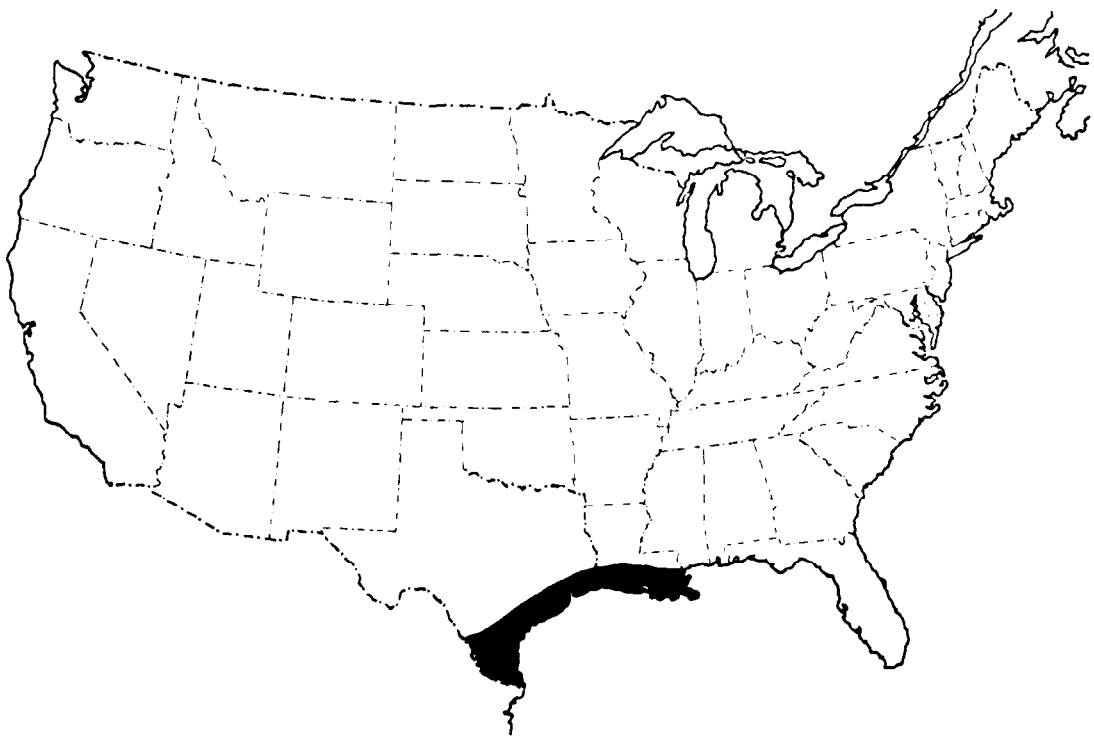
- Waynesburg College (Waynesburg, Pennsylvania): The Waynesburg College contract involves the development of multiple methane production zones in a single well in an unmined extensively developed surface area.

Project activities and milestones for future years are shown in Figure 6.

FIGURE 7


RESOURCE GAS
ACTIVITY ENHANCED GAS RECOVERY
SUBACTIVITY METHANE FROM COALBEDS
TASK
CY 1978
CY 1979
CY 1980
CY 1981
CY 1982
CY 1983
CY 1984
CY 1985
CY 86
FY 1978
FY 1979
FY 1980
FY 1981
FY 1982
FY 1983
FY 1984
FY 1985
FY 1986
Evaluation
Update Estimate of Total Gas-In-Place and Recoverable Gas
Data Base for Priority Basins
Establish
Computerize
Complete
Decision to Continue or Redirect
Complete
Current Program
Resource and Site Characterization
Complete Unmineable Coalbeds
Final Report
Preliminary Resource Assessments
Research, Instrumentation, and Modeling
Complete Testing of Turbodrill
Complete Lab Testing of Explosive Fracturing
Complete Sodium Hypochloride Lab Testing
Complete Testing of the Water Jet Drill and Guidance Equipment
Complete CO_2 Field Desorption Testing
Complete Pressure Coring Experiment
Complete Fracture-Containment Testing
Production Technology Development
Complete Testing for Pipeline
Complete Directional Drilling of "Bird's Foot" Well
Complete 800 kW Power Generation
Complete Space Heating/ Fuel Cell/Gas Cleanup/ Pipeline
Complete Multiseam Completion/Pipeline
Complete Horizontal Borehole/LNG
Complete Western Unmined Coalbed/Pipeline
Complete Multivertical Well Southern Mine Degas/ Pipeline
Complete Western Directionally Drilled/ Pipeline

METHANE RECOVERY FROM GEOPRESSURED AQUIFERS



METHANE RECOVERY FROM GEOPRESSURED AQUIFERS

Methane, the major constituent of natural gas, is slightly soluble in water at standard conditions; however, solubility increases rapidly with pressure and temperature (above 82°C). High-pressured subsurface zones (known as geopressured zones in the petroleum industry) containing water and its dissolved methane thus represent a potential resource base for natural gas. Geopressured zones are found in only a few coastal areas of the world. One of the largest of these zones underlies a large portion of the northern shoreline of the Gulf of Mexico, in a strip 200 to 300 miles wide slightly off the coast of Texas and Louisiana. Here, sedimentary deposits exhibit a maximum thickness of some 50,000 feet in some areas, with the upper 25,000 feet primarily composed of alternating series of rock layers which may be broadly classified as sandstones and shales, and the lower layers consisting almost entirely of shales, which are believed to be the origin of the methane in the geopressure formations.

Because of the many unknowns associated with this resource, quantitative estimates are difficult to make. This uncertainty is reflected in the current in-place-resource estimates which vary widely from a low of 984 trillion standard cubic feet (Tcf) to a high of 50,000 Tcf. Not enough is known at this time to estimate how much of this resource can be economically exploited. Since the geopressured aquifers contain water under high pressure and temperature, additional energy may be extracted in the form of useful heat and hydraulic energy.

The economics of natural gas production from geopressured aquifers depend on many factors such as:

- The prevailing price for natural gas.
- The cost of drilling and equipping deep wells for production.
- The ability of these wells to produce large volumes (40,000 barrels per day) of water over a lifetime of at least 20 years.
- The absence of significant environmental impact, through proper mitigation, at such production levels.

Private industry has not investigated this potentially large resource so far because of the above uncertainties; and, therefore, it is logical that the Federal Government provide the initial effort to a point where such doubts are substantially removed for the private sector to take over further research and development.

The Department of Energy (DOE), through its predecessor agencies, has been involved in geopressured aquifer research since 1974. Currently, this program is being carried out by DOE's Division of Geothermal Energy at the headquarters level, with implementation of various projects being handled by the Geopressure Projects Office, Houston, Texas, and the Geothermal Branch, both of the Nevada Operations Office in Las Vegas, Nevada.

The goal of the program is to stimulate commercial development, by the private sector, of the geopressured-geothermal resource as an economical, reliable,

safe, and environmentally acceptable energy source. In order to achieve this goal, DOE is evaluating production strategies for the recovery of methane from the shallower geopressured reservoirs and for "total energy recovery" (i.e., recovery of methane, production of electric power, and direct heat utilization) from the deeper, higher-temperature reservoirs. Major program activities are aimed at improved understanding of the resource, including the confirmation of optimum reservoirs and the identification and resolution of key engineering, environmental, and institutional problems. If successful, the program will provide the information required by the industry to develop geopressured energy resources beginning in the mid-1980's.

To date, the DOE-R&D program has concentrated on resource characterization. These efforts have resulted in the identification of optimum prospects for reservoir confirmation drilling and testing. On the basis of these accomplishments, a long-term R&D strategy has been developed in cooperation with industry and state and local Government agencies, which is aimed at bringing geopressured-geothermal resources "on line" in a planned and phased manner. This long-term program will cover the following five key areas which are discussed in depth in the continuation of this section:

- Regional Planning.
- Resource Definition.
- Technology Development.
- Environmental Control.
- Facilities.

Regional Planning

Work in this area provides for the analysis of the economic, institutional, legal, and technological framework for geopressured-geothermal energy exploration, development, and utilization, and the identification and assessment of policy options and technical programs to encourage and expedite its development according to the intended schedule.

The major component of this effort is the regional operations research conducted by the Louisiana Department of Natural Resources and the University of Texas at Austin, in cooperation with appropriate organizations within the region, i.e., Federal, state, and local Government agencies, industries, utilities, field developers, and public interest groups. These regional organizations are expected to play important roles in the identification of prospects for detailed evaluation.

This regional operations research program will be supplemented by other regional and national policy programs. On the regional level, DOE will work with cities, counties, and state Governments, as well as the private sector, to assess the legal and institutional barriers to the desired development objectives. On the national level, studies are directed toward determining the federal incentives which would most effectively accelerate commercial development of the resources. Incentives in the form of depletion allowances, investment tax credits, production tax credits, and price regulations have recently been enacted as part of the tax and price provisions of the National Energy Act.

Resource Definition

The work in this area is directed at resolving two major reservoir uncertainties: one, the number, location, characteristics, and producibility of individual geopressured aquifers; and two, the amount of recoverable methane, a key factor in the economics of the utilization of geopressured resources. To this end, the assessment of all known onshore geopressured formations in Texas (Frio, Vicksburg, and Wilcox) and Louisiana (Miocene, Oligocene, and Tuscaloosa) is being conducted by the Texas Bureau of Economic Geology and Louisiana State University, respectively, in order to delineate optimum resource areas for reservoir confirmation drilling and testing. During the period 1979 to 1984, the reservoir confirmation program will consist of drilling and testing approximately four new wells a year specifically designed for long-term reservoir testing in the optimum resource areas delineated in the resource assessment studies. In addition, the program will include testing in up to four existing wells a year to obtain additional data on fluid and reservoir characteristics.

The reservoir confirmation program was initiated in 1977 with the recompletion and testing of the Edna Delcambre No. 1 well, an abandoned gas well in Vermilion Parish, Louisiana. Results of testing of two geopressured aquifers at 12,900 and 12,600 feet at rates up to 12,000 barrels a day indicated average gas production up to 80 standard cubic feet per barrel (scf/bbl), although recombined samples yielded solubilities of approximately 20 scf/bbl. Data from the Fairfax Foster Sutter No. 2, Beulah Simon No. 2, and Pleasant Bayou No. 2 indicate gas production of 20 to 25 scf/bbl and recombination sample data indicate the water is saturated with gas at reservoir conditions.

Technology Development

Efforts in this area are directed toward reducing the cost of developing and using geopressured resources. Some research projects address critical problems that must be solved if exploitation of the resource is ever to support a significant industry. The technology development program is conducted under the following basic categories: direct heat utilization, well drilling and completion, geochemical engineering, advancing heat exchanger development, and advanced energy conversion systems.

Based on the results of the operations research and systems analysis work, which will identify energy markets in the region, a number of engineering and economic studies of nonelectric applications will be initiated. In addition, site-specific application studies will be conducted for those areas selected in the resource definition studies for confirmation drilling and testing. Nonelectric application experiments covering residential/commercial space heating and cooling, industrial processing, and agricultural uses will also be initiated to obtain site-specific and application-specific engineering and economic information.

The other technology development program categories include geopressured-specific as well as broadly applicable (e.g., hydrothermal, hot dry rock) elements. The geopressured-specific elements address problems associated with high pressures, sand production, and fluid chemistry. Broadly applicable elements include, for example, development of high-temperature drill bits, more efficient and low-cost energy conversion systems, and materials research.

Environmental Control

The geopressured-geothermal environmental control program is conducted under two basic categories: one, programs associated with specific geopressured development sites or prospect-specific programs; and two, programs aimed at resolving generic geopressured resource development concerns.

Four types of programs directly affecting the development of geopressured prospects or sites will be conducted in conjunction with well site selections resulting from the resource assessment studies. These programs include: regional baseline studies; environmental data collection and analyses associated with site selections; environmental impact analyses, including preparation of impact assessments and statements; and environmental monitoring.

Environmental concerns associated with geopressured resources are similar to those identified with hydrothermal resources. These concerns include subsidence, induced seismicity, toxic gas release, well blowout, noise, and waste fluid disposal. The research and development activities will be directed to assess which of the concerns are justified and what, if any, mitigating procedures exist to minimize environmental impacts of full-scale development.

Facilities

Results of the reservoir definition studies, together with the information obtained from the operations research activities, will provide the necessary information to enable a decision on whether to proceed with the design and construction of pilot-scale or commercial-sized demonstration plant(s). If the conditions are favorable, it is anticipated that the pilot/demonstration plant(s) will be designed to produce and market electric power, separate the methane, and utilize the remaining heat in the geothermal fluids for direct heat applications. Specifically, the plant(s) will be designed to: demonstrate state-of-the-art technologies; obtain realistic cost data from which operating, maintenance, and production costs can be extrapolated with confidence; provide adequate instrumentation to obtain engineering data; and demonstrate reservoir deliverability and longevity. Efforts leading to the pilot/demonstration plant(s) will involve conceptual design, site evaluation, additional reservoir testing, and environmental studies and assessments.